Measuring Interface and Bulk Spin Diffusion in Platinum with Spin Rotation

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Research Goal:

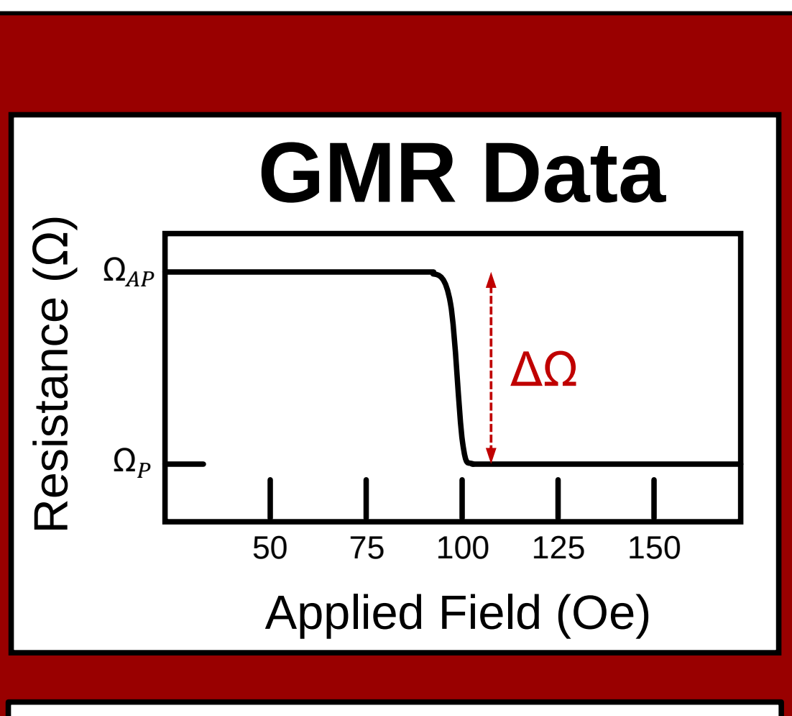
- Previously the spin diffusion length of Platinum has been measured using the current-perpendicular-to-plane (CPP) GMR and the Spin Pumping technique, but with different conclusions:
  2002: 14 +/- 6 nm (GMR by H Kurt *et al.*)[1]
  2012: 1.4 +/- 0.3 nm (Spin Pumping by L Liu *et al.*)[2]
- We believe that the strong interface damping contribution in Platinum has prevented others from observing the bulk behavior with the Spin Pumping technique.
- Using the spin galvanic effect with spin rotation symmetry[3], we have developed a spin transmission based measurement technique, which allows the separation of bulk and interface spin memory loss and the ability to determine λ_{sd} (Bulk Spin Diffusion Length) of Platinum.

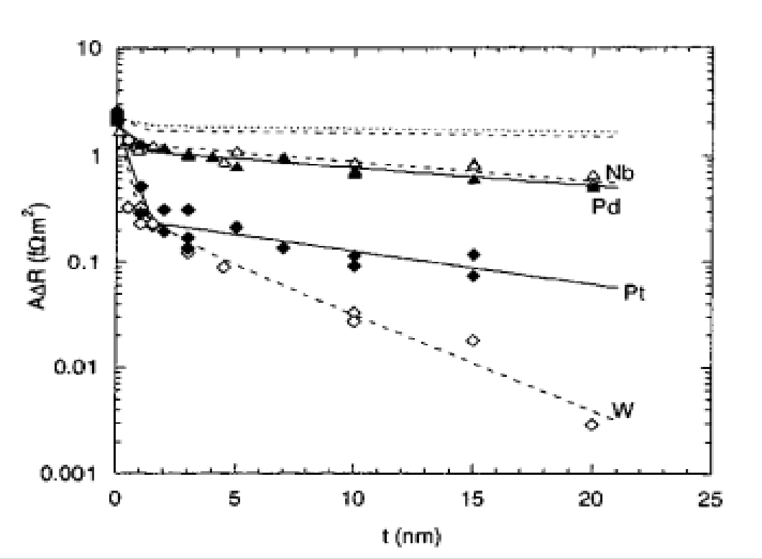
GMR Experiment:

- FM/Cu/Pt/Cu/FM samples with varying Pt thickness are deposited between a pair of superconducting electrodes, to allow current to flow perpendicular to the deposition plane.
- CPP-GMR is measured as a function of the Pt thickness. The GMR ratio is proportional to the transmission of the spin current across the multilayer stack:

$$\Delta\Omega \propto \xi_{Interface}{}^{2} * \exp\left[\frac{-x}{\lambda_{sd}}\right]$$

This technique is accurate even as the GMR ratio approaches zero. However, it requires nanolithography and extremely low temperatures (4.2 K) due to the use of superconducting electrodes.





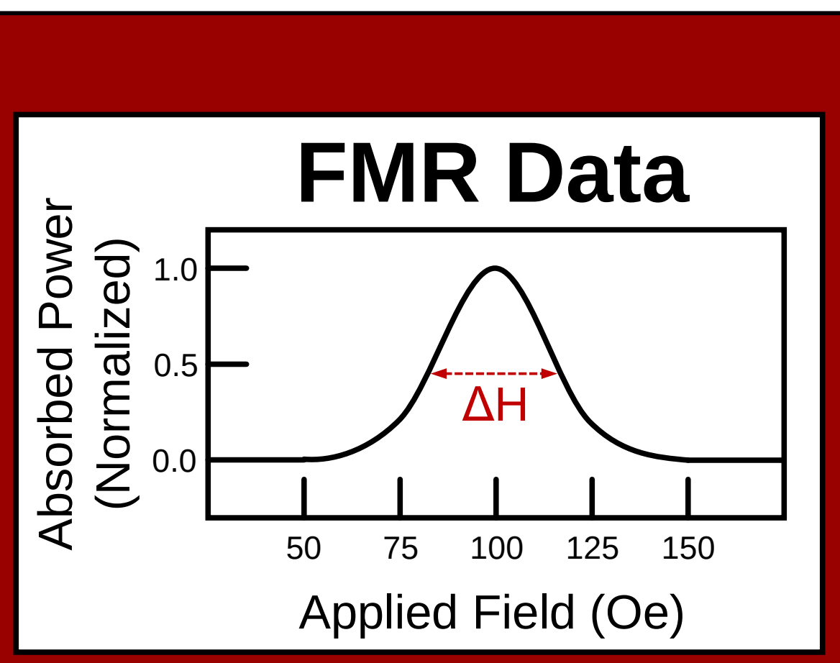
Specific Resistance vs. Pt Thickness
Figure copied from [1]

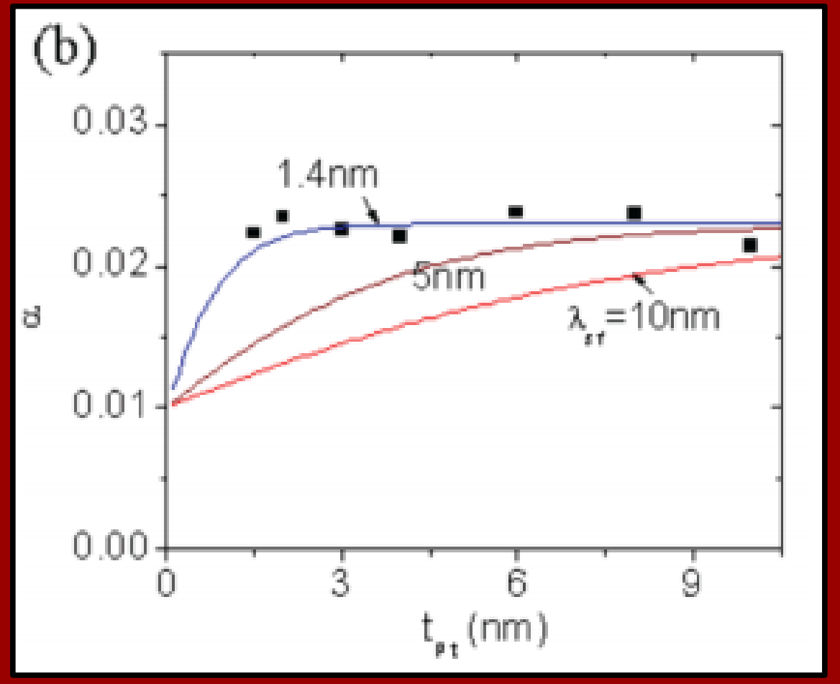
FMR Spin Pumping Experiment:

- In a typical spin pumping-damping enhancement experiment for a ferromagnet (FM)/Pt bilayer, ferromagnetic linewidth (ΔH) is measured. The damping enhancement compared to the FM *without* the Pt capping is attributed to the absorption of pumped spin current.
- The absorption of the spin current can be attributed to both spin memory loss at the FM/Pt interface and at the bulk of Pt. In principle, the bulk spin diffusion length of Pt can be revealed by a Pt thickness-dependent measurement of the damping enhancement:

$$\Delta a \propto \xi_{Interface} + (1-\xi_{Interface})^{2} * (\exp\left[\frac{-2x}{\lambda_{sd}}\right])$$

The main disadvantage to this technique is that it lacks accuracy when spin absorption is close to 100%, because small variations are cloaked by the already large ΔH value.



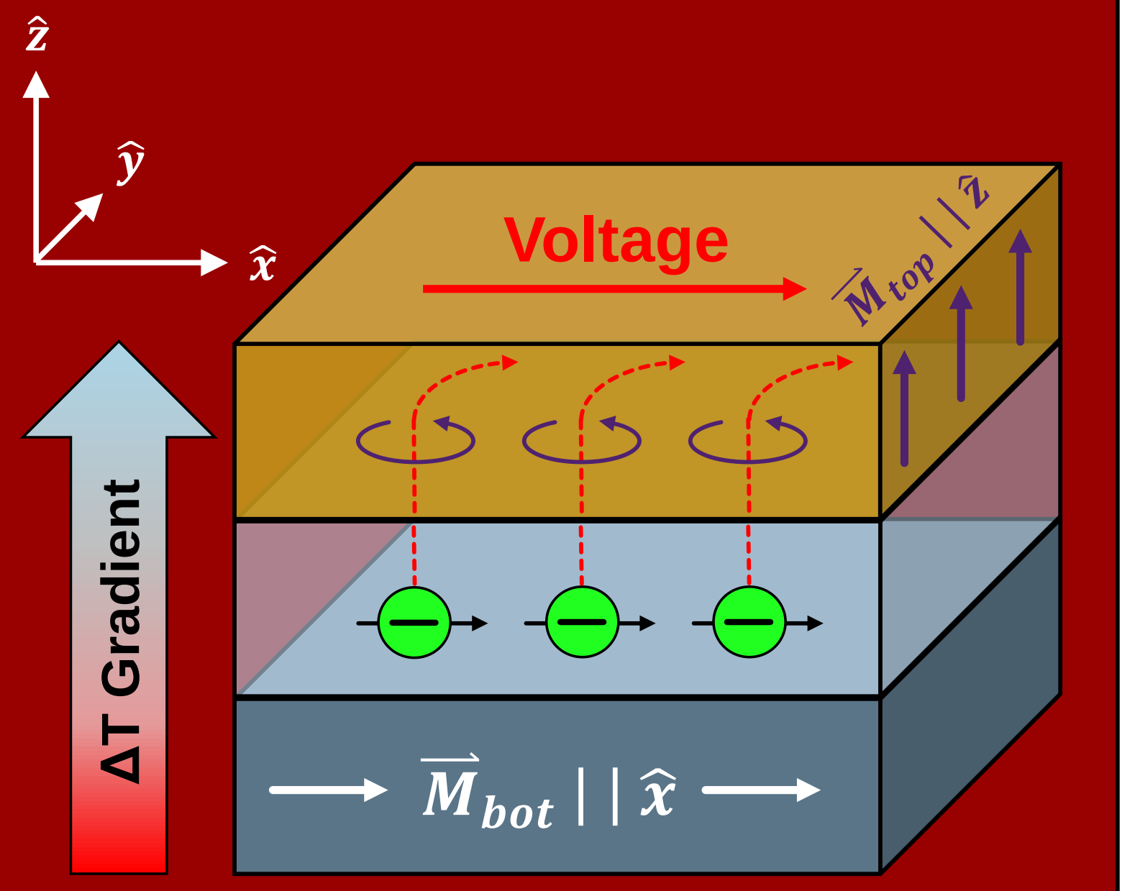


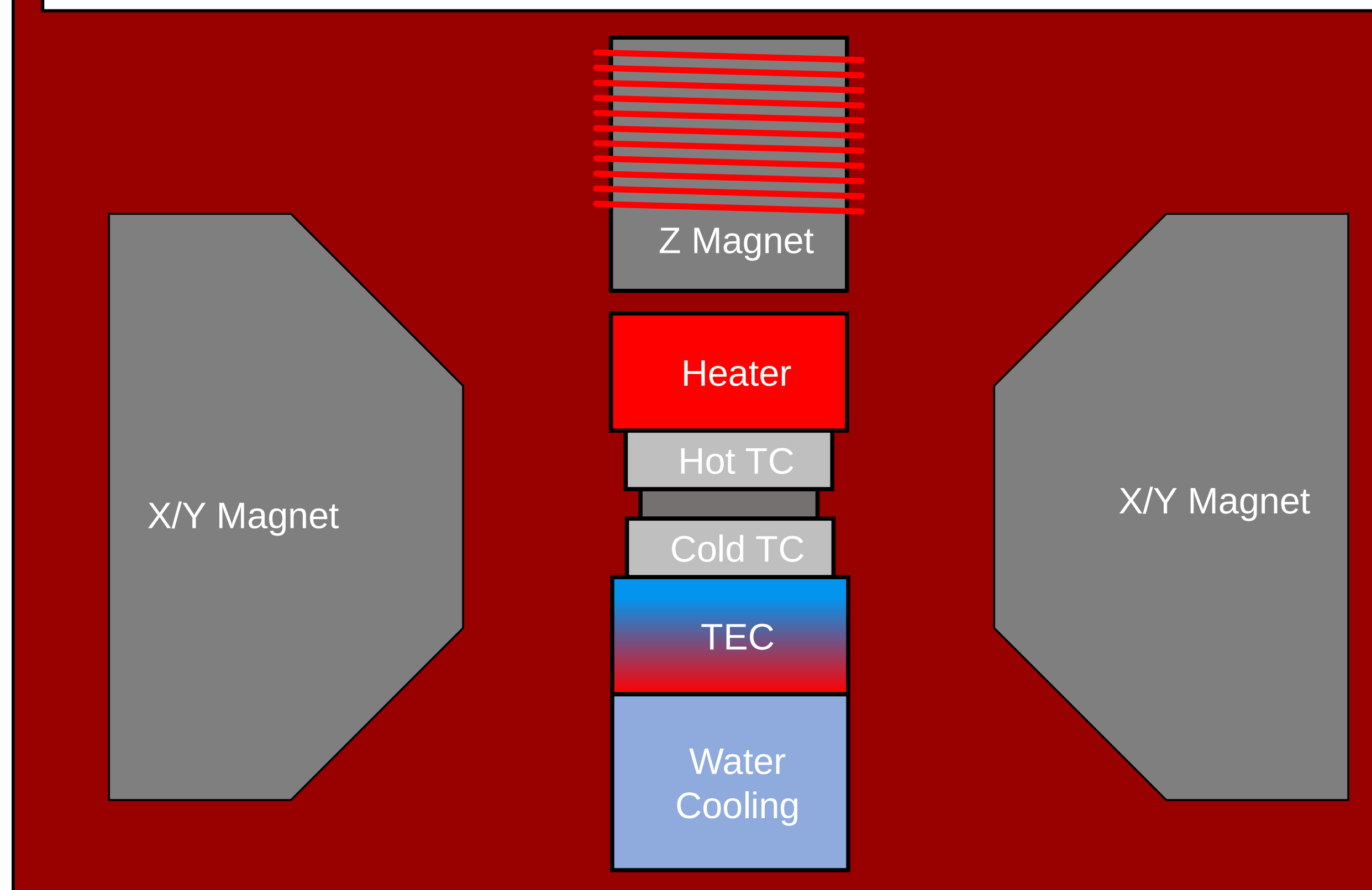
Damping Enhancement vs Pt Thickness
Figure copied from [2]

Spin Galvanic Effect with Spin Rotation Symmetry:

- We recently demonstrated a spin galvanic effect with spin rotation symmetry in a spin valve[3].
- A spin current generated by the spin Seebeck effect (SSE) can flow from one magnetic layer across the spacer to generate an in-plane voltage in the second magnetic layer, in the direction orthogonal to the conventional Nernst and SSE-inverse spin Hall effect voltages.

This voltage is proportional to how much spin information is retained after passing through the spacer layer, similar to the GMR experiment. With a thickness dependence study we can determine λ_{sd}^{Pt} very precisely.

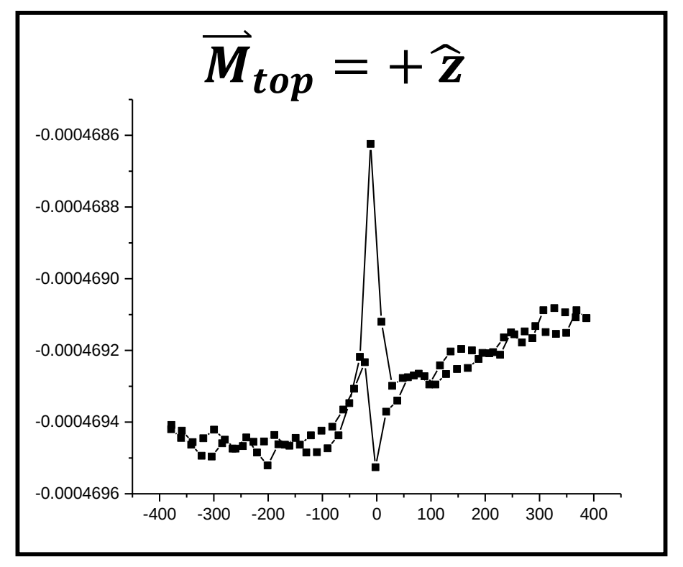


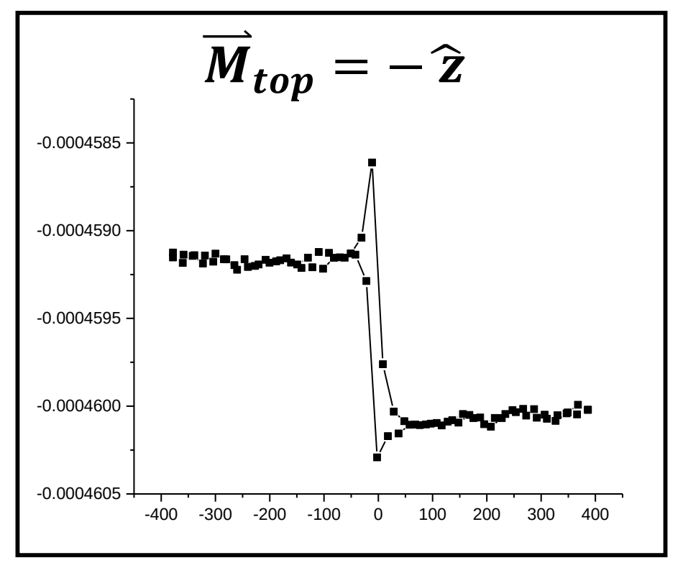


Apparatus:

- A Peltier element (TEC) and CPU water cooling block are the heat sink.
- An Aluminum block with an embedded thermocouple measures the cold side temperature.
- Another Aluminum thermocouple block measures the hot side temperature.
- A resistive heater is the heat source.
- A plastic capping piece with spring-loaded screws keeps the entire stack compressed.
- Above the stack is a handmade electromagnet, to switch the out-of-plane layer’s magnetization.
- On either side are the X/Y electromagnet poles, free to rotate about the stack from $\vec{H} \,||\, \hat{x}$ to $\vec{H} \,||\, \hat{y}$.

Preliminary Results:



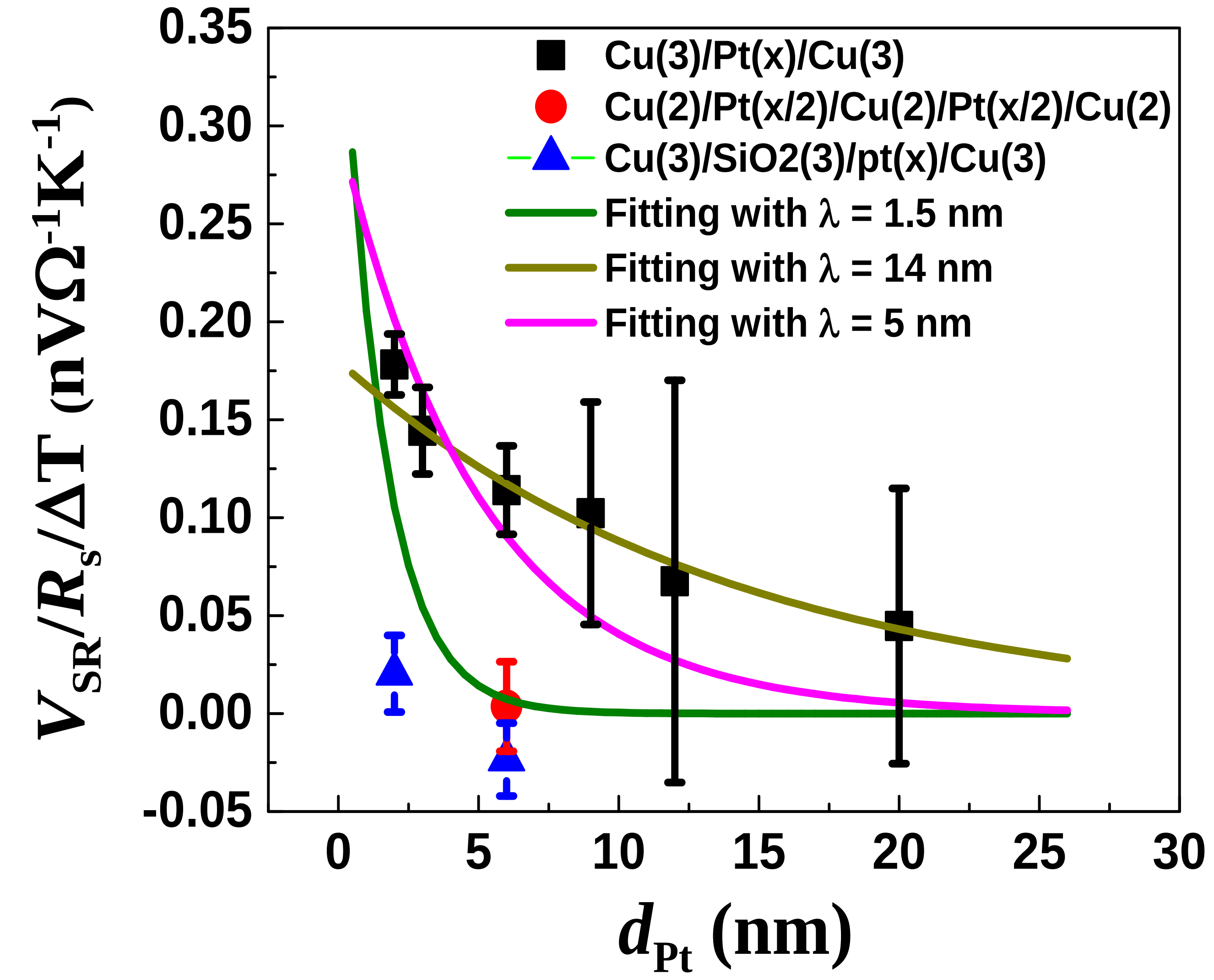


- Our suspicion is that the interface damping contribution of Pt is large compared to the bulk component.
- By only using data points from samples with complete interfaces (t > 3nm) we can separate the bulk damping contribution and thus $\boldsymbol{\lambda_{sd}}$:

$$V \propto \xi_{Interface}{}^{2} * \exp\left[\frac{-x}{\lambda_{sd}}\right]$$

$$For\ 3nm \le x \le 20nm: \lambda_{sd} = 14 \pm 1.5\ nm\ Pt$$

- We have verified our results multiple interface tests as well as with SiO_2 spacer layer tests.



References and Acknowledgements:

[1] H. Kurt, R. Loloee, K. Eid, W. P. Pratt Jr., and J. Bass, Appl. Phys. Lett. 81, 4787 (2002).
[2] L. Liu, R. A. Buhrman, and D. C. Ralph, arXiv:1111.3702 (2012).
[3] A. M. Humphries, T. Wang, E. R. J. Edwards *et al.*, preprint at arXiv: 1704.08998 (2017).

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